Intelligent Control of Robotic Systems through Sensor-Actuator Integration Using Artificial Intelligence

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

by

Naveen Kumar
MRUECDN012K210061

Under the supervision of

Dr. Niharika Thakur
Associate Professor

Dr. Yogita Gupta
Manager, Kohler, Gurugram

Department of Electronics and Communication Engineering
School of Engineering

MANAV RACHNA UNIVERSITY
Sector-43, Aravali Hills, Faridabad

Year ***2024***

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It is the work that is expected to be carried out under the supervision of **Dr. Niharika Thakur** and co-supervision of **Dr. Yogita Gupta.**

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Naveen Kumar

Registration Number:- MRUECDN012K210061

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Supervisor
Dr. Niharika Thakur
Associate Professor

Co-Supervisor
Dr. Yogita Gupta
Manager, Kohler
Gurugram

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Abstract

The controlled motion of a bilateral Teleoperation is investigated in this work in the absence/presence of time delays in their communication channel. The system shows stability theoretically as well as simulation in the absence of time delays while it causes the system to become unstable due to communication delays. The controller has been designed using a passivity-based method. The stability of Teleoperation without and under the influence of time delays has been investigated. The stability has been analyzed in Teleoperation with/without time delays that demonstrate stability/ instability. The slave tracks the master's desired motion in the absence of time delays that has been analyzed theoretically as well as simulation in this work while the slave does not track the master's desired motion, causing instability and decrease in system performance. A wave variable-based strategy is employed to ensure the system's stability to compensate for time delays and increase the system's performance. Stability analysis has been done under the influence of time delays and the same with simulation with different values of controller gain for optimal result. Number of iterations used for optimal value of controller gain. In this work, after incorporating the wave variable approach passivity/stability deteriorate if gain values is used different from the optimal values

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1. Introduction

One of the first subfields of robotics may be tele-robotics. Up until the 1980s, the emphasis had been mostly on the space, underwater etc applications since its modest beginning in the 1940s with the design of the first tele-operator. Recent advancements in processing power and connection have led to the emergence of unique applications such as telesurgery, semiautonomous telerobotics, and others.. The branch of robotics known as tele-robotics is focused on remotely controlling robots, primarily using wireless links. "Doing work from a distance" is what is meant by the term "teleoperation." Unilateral and bilateral teleoperation systems can be loosely split into two categories. Bilateral denotes that the robots are actually engaging with each other, as opposed to unilateral, which describes how one robot is providing data to another but not receiving anything in return.

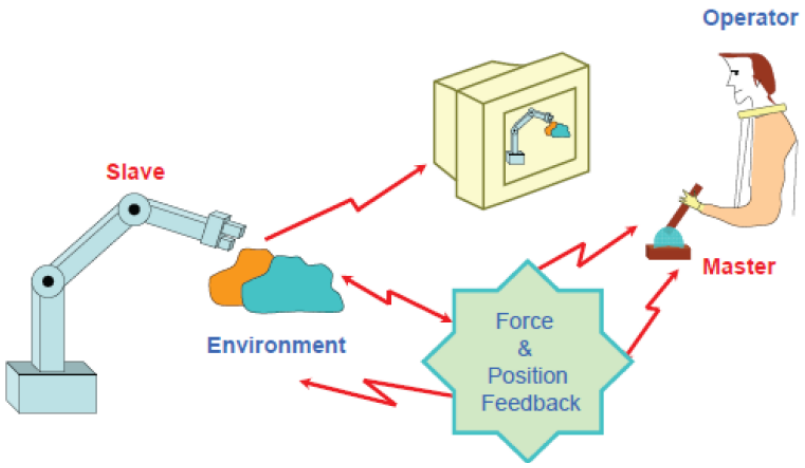

Fig.1. Bilateral teleoperation system [3]

A typical teleoperation system is shown in Figure 1 and consists of a human operator, a master operating stick at the operator's location, a communication channel that enables the exchange of force and position data, as well as visual feedback from the camera at the slave location that is displayed on the monitor at the master location. In this system, control instructions from the master to the slave and feedback from the slave to the master can be transmitted using electrical impulses carried through wires, wire networks, or wireless networks. [4].

2. Literature review

The study of bilateral teleoperation is more than 50 years old with the first ideas being developed in mid1940's [1]-[7]. The first master-slave teleoperator was built by Goertz, and from then on it has undergone immense transformation. It basically helps us understand more about human-robot [8] interactions and connects the fields of control theory, communication, artificial intelligence and robotics.

In addition to controlling unmanned underwater vehicles, handling hazardous items, and guiding mobile robots with obstacle avoidance, bilateral teleoperation has been applied in many different fields. [1]

The handling of radioactive materials was the first application of teleoperated manipulators. Motion scaling, visual feedback, and force feedback were the primary goals. Even more recent developments in this field serve as the foundation for several studies. [6]

It has also been extensively used in telesurgery. The concept is to allow a surgeon at one place to perform surgery at a remote location. This saves time, money and effort. However time delays form a major concern in such systems.

Recent developments in bilateral telerobotic have led to an increased use in the fields of underwater vehicles [7] and space robots. They find applications in scientific explorations and military applications taking the frontiers of science to new levels. They are advantageous because they eliminate the need of using tethers which limit the mobility of the vehicle and may also cause the problem of entanglements.

When bilateral telerobotic systems were first developed, stability and precise tracking were the key problems. Time delays in the communication channels were shown to have an impact on the system's stability. In order to ensure the teleoperator's passivity[9]-[10], various strategies have been developed. One approach relies on creating PD-type controllers[4]. It was proven to be a practical method for accurate tracking and to guarantee system stability.

The Scattering Parameter based technique was born out of this [11]. Even in the face of system time delays, this technique was able to provide effective tracking and ensure system stability. However, the maximum delay for which this approach could be employed had a time limit. When it was discovered that the delay exceeded this time bound, the scattering parameter-based strategy failed.

The development of damping injection methods was one of the improvements made with PD

type controllers [12]. According to the physical interpretation, there are virtual springs and dampers in the link between the local and remote manipulators. If the gains are properly selected, it enables asymptotic stability and offers position tracking for time delays that are either constant or variable. They were discovered to be sensitive to sudden changes in time delays, though. Injection of damping may also cause the response to become sluggish.

The Wave Variable based approach [6] was another method. They provide resistance to arbitrary delays in time. They can handle unidentified models and significant uncertainty and are suited to nonlinear [13] systems. It renders the system resistant to temporal lags. With longer time delays, it was discovered that the system's tracking performance declined. In contrast to the Scattering Parameter technique, the system would always be stable, which was a significant advance.

Numerous studies comparing the effectiveness of various strategies used for the stabilisation of bilateral teleoperation have been conducted [14]. The major goal of such a study is to provide a comprehensive theoretical framework that enables the investigation of the stability of all the existing literary systems.

The conventional deep learning techniques are rarely used for bilateral teleoperation but also the neural networks are advanced in automation [14], image processing [15], face recognition [16] etc. With its unique layers and self-command capabilities, the neural networks have widely used in robotics, artificial intelligence, communications etc. The neural network should be beneficial with adaptability and fast learning ability. The Author [17] uses An Artificial neural networks (ANNs) for to model the map multiple relationship for master and slave. The conventional ANN network consists of containing several layers. Every artificial neuron or node is connected to each other and has similar threshold and weight. The specific node is started if the threshold value of any particular node is specifically high; else the data will not pass to the next network layer. Deep Neural Networks (DNN) used by the Author [18] for the multiple layered antonyms with complex formation of layers. The basic discrepancy between DNN and ANN is that the large number of nodes are connected and the difficulty of connection in each layer, so for complex issues, high power is needed. DNN recognizes key things in the distant working environment, allowing the physical characteristics of such objects to be associated with their recognition for enhanced interactions during robot teleoperation. Multi-layer perceptron (MLPs) [19] or Feed forward

neural networks (FFNN) [20] are developed from sigmoid neurons. The future location of a slave can be predict by the conventional FFNN network so in teleoperation system, it will reduce latency time. These neural networks are comprehended from hidden layer or layers and input and output layers. FFNN network is a substructure of natural language processing. The Author [21] is specially designed RBFNN (radial basis function neural network) for tracking master and slave performance under specific conditions. The effect of the external disturbance is isolated through the disturbance-observer modelling, while an RBFNN approximation is designed to correct and approximate modelling uncertainties. The RBFNN is one of forward neural network which consist of three layers hidden layer, output and input layer. Fast convergence is the advantage of this type of algorithms. The Author [22] used the RNN (Recurrent neural network) for beating-heart surgery as the medical field. The RNN is used to predict the heart motion for the surgical activity. RNN is a neural network which the input is given from the output of the previous step. RNN is used in real time communication but due to its complex training procedure and slow system it is difficult to implement the system from RNN.

The evolution of the robotics and automation techniques, the dangerous, unstructured and remote application areas is controlled by the human operator using the bilateral teleoperation system [23-26]. It is also widely used is various applications such as subsea exploration, nuclear detection, military operation, and medical surgery [27]. The modules like environment, slave, communication channel, master and human operator together constitute the general bilateral teleoperation system [28, 29]. The communication channel is utilized for transferring the long distance information transmission to the slave from the master makes some delay in terms of time. Such time delays may limit the processing of the system [30]. So, to overcome such issues in bilateral operation system effective and novel control algorithms must be implemented to enhance operation of the model based on the assessment measures like tracking the position and feedback of force for the transparency measure. Therefore, a novel control algorithm is proposed by considering the issues such as time delay, passivity, uncertainties, and nonlinearities and to attain good transparency performance and stability of the teleoperation systems.

3. Motivation

The human presence in a variety of domains where it previously risky to travel has decreased as a result of recent advancements in telerobotics, including exploration missions, hazardous environments, etc. This prevents unwanted human exposure to potentially hazardous environments while also being inexpensive and safe. The decommissioning of nuclear power plants, toxic waste cleaning, search and rescue operations, and security, surveillance, and reconnaissance duties are a few examples of popular applications [20] that contain components of danger where human casualties are probable or even likely. It is desirable in all of these applications to deploy telerobotic system technology to lower the risk to humans. The technology of bilateral teleoperation is employed in the realm of medicine for telesurgery[21]-[22]. The applications mentioned above are just a few of the numerous recent developments that are taking place in this industry, making it a fascinating one to work in.

4. Description of research work

The block diagram of a typical bilateral tele-operation is shown below

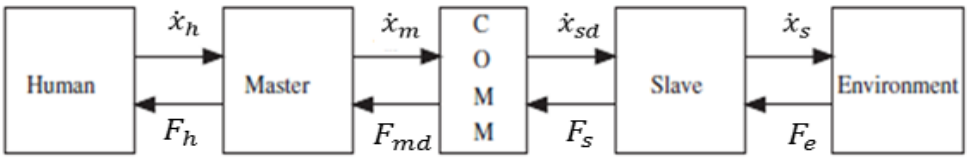

Fig.2. Block Diagram of Bilateral Tele-operation System

Figure 2 consists of the human operator, the master, the communication block, the slave, and the environment are its subsystems. The master is given a forceful command by the human operator to move quickly, and this command is transmitted to the slave via the communication block. If the slave makes contact with a remote environment, the slave side communicates the remote force back, which the master side then receives as the force. The local controller, which is located at the slave end, gauges the force of the environment and notifies the master side. The teleoperator is controlled bilaterally, therefore the arrow is reversed which is shown in Figure 2.

5. Research Objective

- To Study the various intelligent controller used in robotic system
- To design and implement a controller using various approach for improvement of system performance in the presence of time delays.
- To design and implement an AI-based controller for a robotic system.
- To assess the performance of the AI-based control system in comparison to conventional control techniques.

6. Problem description

The main goal of this research can be summarized as

- Understanding the theory behind bilateral teleoperation
- Studied the effect of time delay in communication channels on system performance
- Stabilize the system in presence of time delays by understanding and simulating different approaches present in literature.
- Scattering parameter techniques has been exploited for stabilization of the system.
- Basic/Traditional Controller (PI, PD, PID) design using scattering approach in tele-robotics for precise tracking of motion and force of the master but this is not suitable for large time delays
- Basic /Traditional controller is not good enough to stabilize and precise tracking. The performance is also compromise with basic controller in the presence of time delays.
- System performance is also affected while considering disturbances.

7. Problem formulation

(i) Master-Slave controller design

Two systems, i.e mass-spring-damper systems are operating as a master-slave teleoperator in this section. Feedback controllers are made to follow the master's location without a lag in time. On both sides, a master controller and a slave controller, there are two PD controllers created.The slave robot's force feedback is handled by the master controller when it comes into touch with an environment as shown in figure 3.

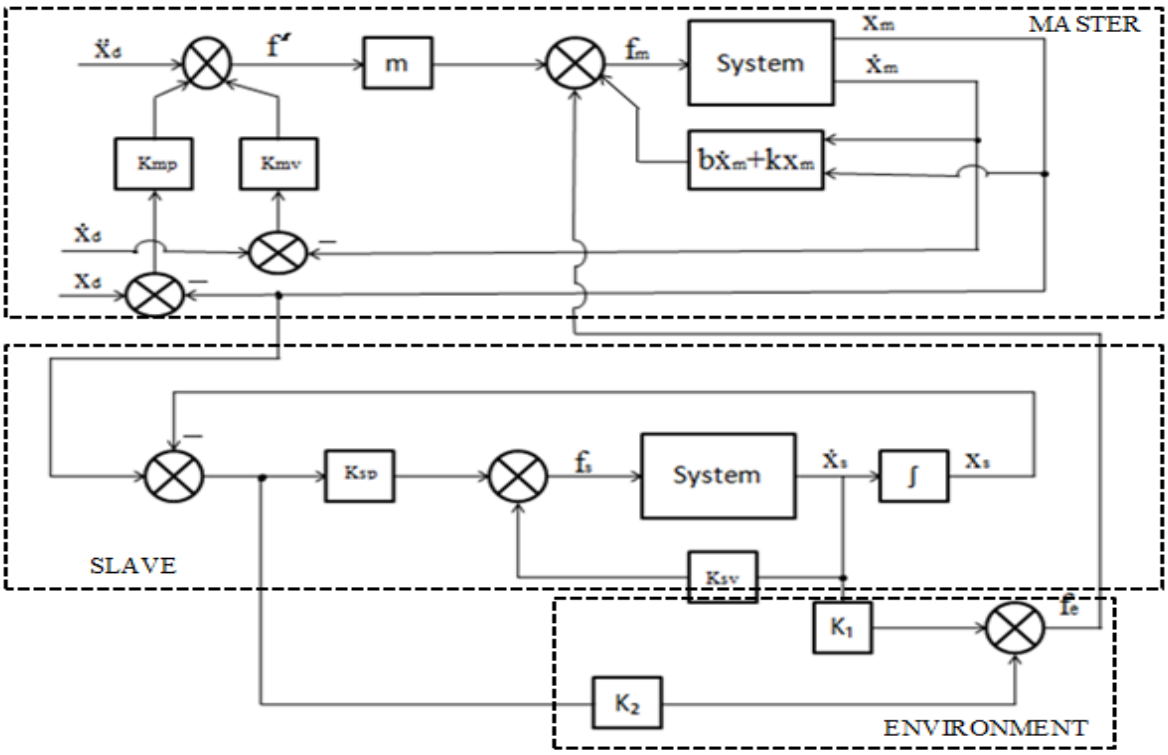

Fig.3. Bilateral Tele-operation using two mass-spring-damper system

In order to take care of time delay, a tele-operation system is shown in figure-4. The source of delay is due to the communication channel between master and slave system. It was seen through simulation that system becomes oscillatory, even unstable due to the presence of delay.

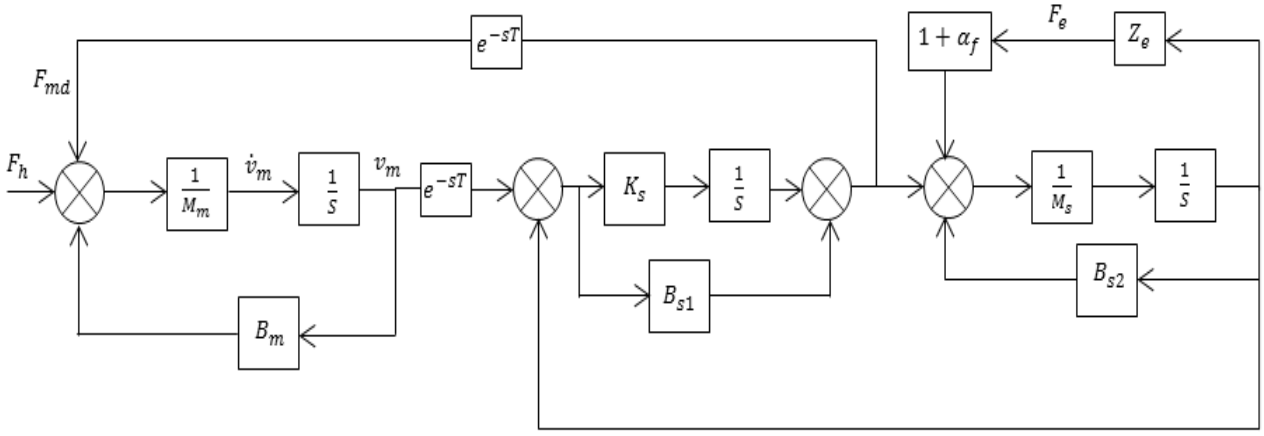

Fig.4. Time delay teleoperator without compensation

To compensate the delay, a controller design is carried out based on scattering parameters [2] as shown in fig-5. Controller parameters are selected to ensure the passivity of the overall closed loop system [8]. Again, simulation was done to show the efficacy of the control algorithm.

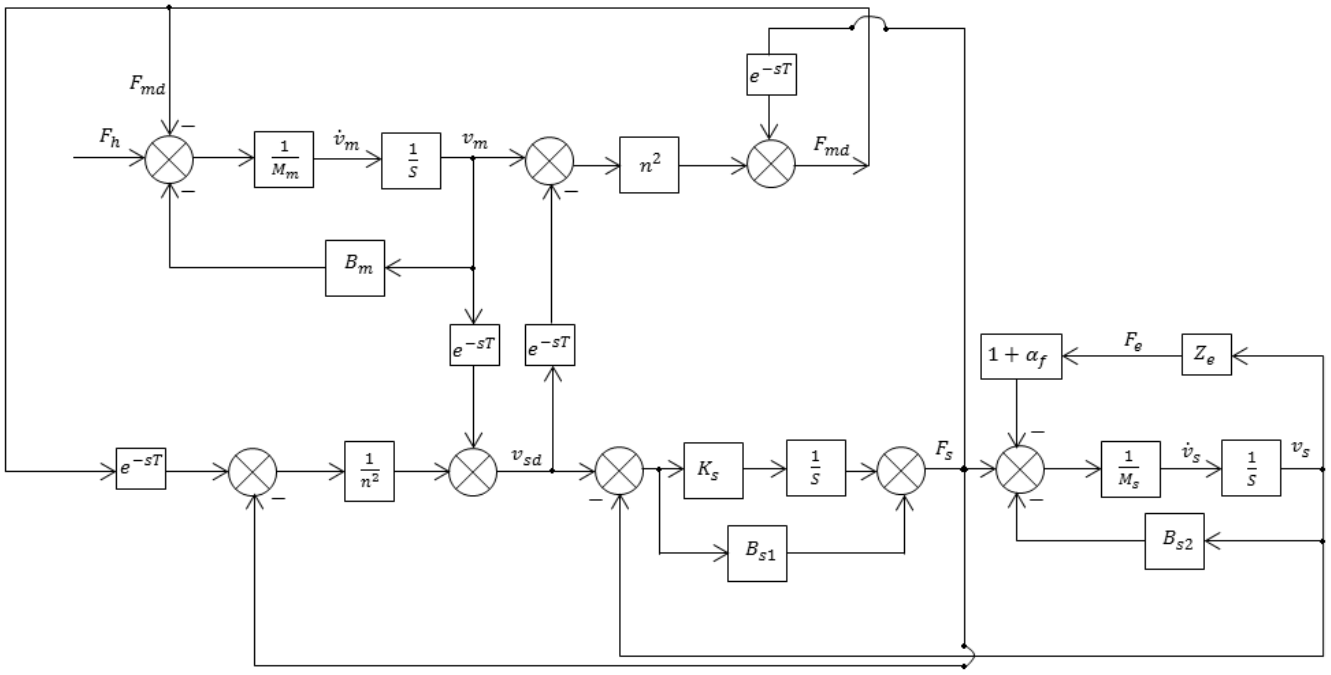

Fig.5. Block diagram of delay compensated bilateral Tele-operator

(ii) Wave variable based controller design

In this approach, wave variable/scattering parameters (adopted from circuit theory) are used for designing a controller[6] for robotic manipulator. In this approach, power variable i.e., velocity and force are first transformed into wave variable before passing through communication channel. Wave variable is retransformed into power variable at receiver end. This transformation based controller ensures the stability and makes system time-delay independent. In Figure 3 shows the block diagram based on wave variable transformation method.

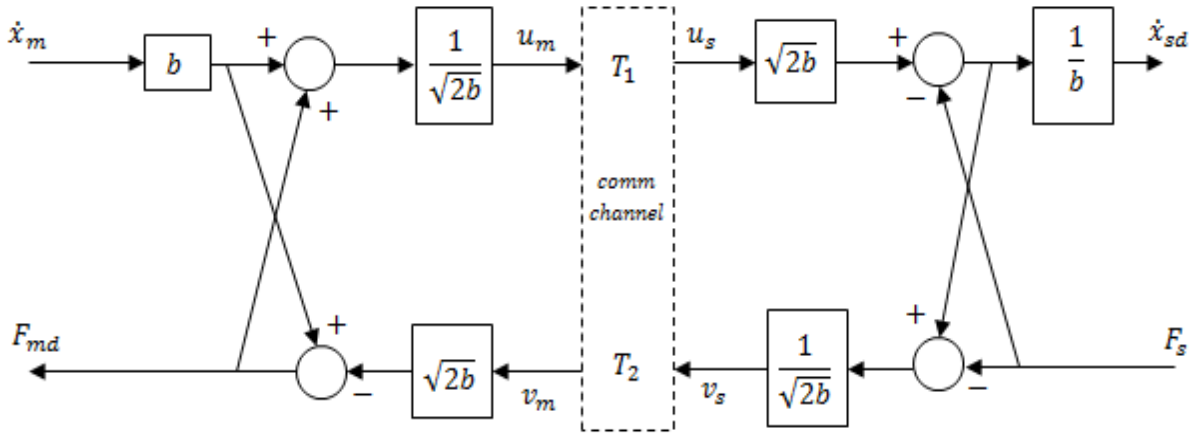

Fig.6. wave variable-based transformation

Simulations are carried out on a tele-robotic system to verify the efficacy of wave variable based controller design.

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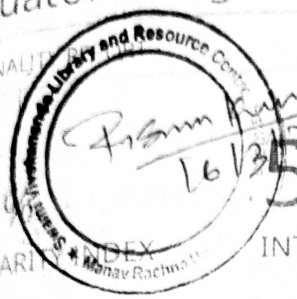

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